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Folding furniture:

From design to production

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Contents

‘Abstract

This thesis introduces research on collapsible furniture. It focuses on foldable furniture, aiming to have an eligible source of information, for readers to acquire facts from folding furniture’s first appearance, evolution facts, as well as, the current trends in this industry. Folding can occur in different ways depending on factors (way of folding, production constraints, aim of usage) that affect directly the selection of materials, fabrication, and mechanisms best suited for each occasion and need. Furthermore, physical prototypes will be fabricated to extract knowledge on the production method and assembly, which are also presented through an image gallery. Through this thesis reader may have a better insight of folding furniture as item of everyday living as well as a better understanding of production methodology of such kind of furniture. Future trends and potential extent of this work are listed in the end.

Keywords: foldable, folding, space-saving, furniture design

‘

Introduction

During the industrial revolution, a great amount of people was flocked to cities. This resulted in the expansion of apartment living and restricted space living. The flooded population in cities led to the majority to live in limited, cramped spaces. Nevertheless, apartments and vertical living still dominate cities. Therefore, folding furniture would be an effective way and a great necessity for saving space while maintaining the essentials for users and improving their lifestyle in a small place.

Furnishing that is collapsible or transformable for saving space purposes is considered one of the biggest challenges for both industrial and architectural design. (Vandoros, 2017).

“Man, himself a collapsible being, physically and psychologically, needs and wants collapsible tools” (Mollerup, 2001).

The appearance of folding furniture can be dated back to when folding chairs first reported.

Folding chair was a common piece of furniture from the ancient times. Such kind of furniture was usually made of wood and less frequently from metal. Archeological evidence of folding chair applications was spread across the Mediterranean region from 13th century. (Duprey, 2004). The furniture became widespread during the Middle Ages. During 15th and 16th centuries the folding chair had several modifications including the addition of headrests. In the United States, an early patent of folding chair was made by John Cham, in 1855. By 1947, Fredric Arnold created the first folding chair with a framework made from aluminum with fabric strapping for the seat and back. During the decade of 1950 folding chair production was increasing with more than 14,000 chairs per day. Nowadays hard plastic is the dominant material along with metal and wood (Schulz, 2012).

Folding chairs, as well as folding furniture in general, can be divided into different categories, depending on the way the piece of furniture collapse, such as paper folding (origami), pop up designs and sliding oriented designs.

1.1 Aim

The aim of this study is to study foldable furniture art, initially how folding furniture entered in peoples’ lives and the efficient role they possess from the first collapsible piece of furniture till nowadays extraordinary smart ergonomic solutions for saving space.

Furthermore, this research aims to demonstrate a series of different kinds of foldable furniture for different environments, spaces, and usage.

Research questions

- What is foldable furniture (types)
- When and how did foldable furniture emerge
- What is the current state of the art of foldable furniture.
- What are the benefits of foldable furniture with regards to:
  a) Fabrication
  b) Packaging
  c) Use
- What mechanisms are used in the production of foldable furniture
- Has the DIY movement played a role in the development of furniture
- What is the future of foldable furniture

1.2 Scope

The general scope of this thesis is to acknowledge the evolution of furniture design, the progress of utility in furniture constructions that combine mechanics' applicability, sustainability, durability, and aesthetics.

In order for the functionality to correspond with the aesthetics, architecture accomplishments assist in furniture design. It is very common for architects to be driven by the actual environmental conditions in order to adapt. Moreover, designers get oriented from some of responsive architecture's rules, too.

"Responsive architecture" term was invented by Nicholas Negroponte in the mid-seventies (Soft Architecture Machines) when spatial design problems were explored in responsive space (Sterk, 2003).

Consequently, as architecture evolves, interior planning changes, spatial arrangements become of great demand, and manufacturers have all the means needed to succeed with numerous furniture solutions for spatial problems or needs.

Leonardo Da Vinci is one of the first designers that was active in the area of engineering mechanics studied the design methodology of transformable constructions. Many of his ideas were inspired by nature indicating the importance of the natural world in the evolution of technology. (Foster H., Krauss P., Bois Y.A., Buchloh H., 2007).

One of the most challenging, yet interesting, tasks for humans seems to be the combination of folding with functionality, as it can be compared with a 3D puzzle which accommodates great research and multiple constraints. The types of folding pieces of furniture are various, according to folding way, to hinges and to materials.

This thesis' intention is to analyse this subject from as many as possible perspectives. The interdisciplinary approach is verified by the need for a comprehensive knowledge of the study of foldability, gathering information from different fields, thus avoiding main information gaps.

Subsequently, folding in furniture is going to be explored through scopes, such as the user's scope, the marketing scope, the designing process, and the production aspect scope.

The manufacturing methods will also be analysed, as well as the materials used. Last but not least, the market will be researched on what kinds of folding furniture are most frequently produced and sold, as the current furniture industry offers great opportunities in satisfying any spatial need.

All in all, driven by consumer behaviour and consumer needs, design methodology encourages innovative ideas to be generated and produced in the furniture industry.

1.3 Methodology

This thesis employs different research methods, including the study of bibliographic sources on materials, fabrication, mechanisms and production, market research with the study of sales reports and data collection that reflects consumers' needs. The initial bibliographic research gathers information on the thesis subject.

Qualitative and quantitative research methods shed light on aspects of the market, such us complaints for dysfunctional or unsustainable products that bibliography cannot clarify, and concerns both the suppliers and the consumers' behaviour.

Summarily, these are:

- Literature review
- Qualitative and quantitative research methods
- Design research

These methods are used to collect information, thereby gaining a deeper understanding of the topic and drawing conclusions that can both be used for future research.

1.4 Dissertation structure

This study consists of 4 chapters, as follow:

The first chapter includes the aim and the scope of this dissertation, followed by the methodology. In the first chapter, there are some examples of folding furniture, ending with the dissertation structure.

The second chapter begins with a literature review constituted by a brief definition of foldable furniture and their types, ensued by the sub-chapter of the precedents in foldable furniture design.

Following the current state of the art of folding furniture is presented, with a subchapter of examples given, to identify the trends. Closing the second chapter, there is information about the future of foldable furniture.

On the third chapter there is research and conclusion on some case studies, based on analyzing the design to production workflow, the prototypes, and the findings, through the selection and the design of case studies.

The fourth chapter has the synopsis and conclusion.

2 Literature review

Historic reports place the appearance of folding furniture back to 15th-13th BC (Duprey, 2004).

Overpopulation and economic factors forced mankind to live or work in restricted spaces, which made space-saving techniques imperative.

Designers, in collaboration with engineers and manufacturers, sought and developed solutions for space-saving, like folding furniture.

Research papers, studies and books have been written about folding principles (Greevenbroek, 2018), design methods ((Jackson, 2011), materials (Wagner, 2018), and mechanisms (Maziar Asefi, n.d.), in order to have reference points to understand and develop the best possible design solution.

This thesis aims to collect and sum up information regarding the main categories of folding furniture, the methods and means of folding and the market demands. Also, aims to be a reliable source for studying the design to production workflow.

2.1 Definition of Foldable furniture and types

Space-saving furniture pieces are widespread for a long time, in our daily lives, vacation, workplaces, even at schools or automotive vehicles. Transformable, collapsible, or foldable furniture provides effective space-saving and portability. Deployable structures are capable of varying their shape automatically from a packaged, compact configuration to an expanded one with operational capabilities when it's needed (Singh, 2007). Through the past decades people's needs led them in resourceful solutions to make living easier and comfortable, therefore saving space does not depend on downscaling but on efficient ways of collapsing a piece of furniture. Among the many space-saving methods such as stacking, implosion and bundling (Mollerup, 2001), folding is possible the most frequently met on furniture.

Such furniture aims to respond to the constantly changing needs of portability and functionality. In general, such a piece of furniture comes in the form of lightweight and deployable structures that are able to transform between various configurations with a safe and easy manner. This ability promotes functionality when and where it's needed (Temmerman, 2014).

As was said previously folding principle is considered one of the easiest ways to employ, and thus it is well established in the furniture market. There are almost infinite ways to transform an interior or exterior space by using folding surfaces, flexible materials or linear components. Models with folding parts are considered an economical and sustainable solution, because of the straightforwardness of their application, linear and radial movement of the folding elements, which can reduce the use of complexed parts and facilitates easy maintenance.

"In recent decades, designers of all disciplines have experimented in folding techniques to create handmade or manufactured objects both functional and decorative" (Jackson, 2011).

"Folding furniture benefits comes from their ability to change state and facilitate new functionality; all within a single system" (Singh, 2007).

2.2.1 Precedents in Foldable furniture design

The precedents that brought the evolution in folding for furniture, are not clearly distinguished, but there are revolutionary examples to detect as critical influences.

Led by space-saving critical need, furniture designers had to develop practical design solutions. One way to succeed in saving space that designers came up with, initially without mechanism usage, was furniture that could stack one onto another.

By the 1963 Robin Day designed the most famous stacking chair, for a firm called S. Hille & Co. It was manufactured using polypropylene through the injection molding process, hence its popular name “polyprop” (fig.1).

Figure 1, Polyprop chair (source :https://design-technology.org/polypropchair.htm)

Polypropylene is lightweight thermoplastic, with high impact resistance. Robin Day’s invention was called stacking chairs as they can be stacked on top of each other.

The Hille chair was a pioneering creation combining cheap and sturdy. It is one of the very few types of chairs that is still being produced, in various modifications, even after half a decade of its creation.

Robin Day was asked by Hille to create a low-cost stacking chair which could be mass-produced, to be easily affordable by anyone who wished to purchase one, also to meet virtually all sorts of seating requirement.

The stacking chair has been used by people in 40 countries around the globe. Its iconic status was validated when it was selected between designs, in a 2009 series of British stamps of “British Design Classics.” The stacking chair was first launched in the market two years after it was designed, in 1965 and won the Council of Industrial Design award.

The development of the chair was to be furthered with the chair to be available in a variety of colors, although when it was first created, it was only in black or red.

Nowadays, the polyprop stacking chair is a popular seating option at schools, offices, hospitals, airports, convention centers, arenas, and even at home. Polyprop stacking chair is considered to be one of the best-selling chairs in the world, while 14 million units were sold, while still counting.

There is also the wooden variety of stacking chairs, such as the popular Ben stacking chair (fig.2).

It was first made for mostly outdoor living areas, though it became a vintage piece of furniture for every space and taste.

Figure 2, Wooden 50's stackable chairs, (source: https://www.vinterior.co/listings/1950-s-tecta-stacking-chairs-set-of-six)

Multiple materials (fig. 3), different kinds of furniture (chairs, tables, stools) evolved according to stacking ability, followed by the generation of folding furniture.

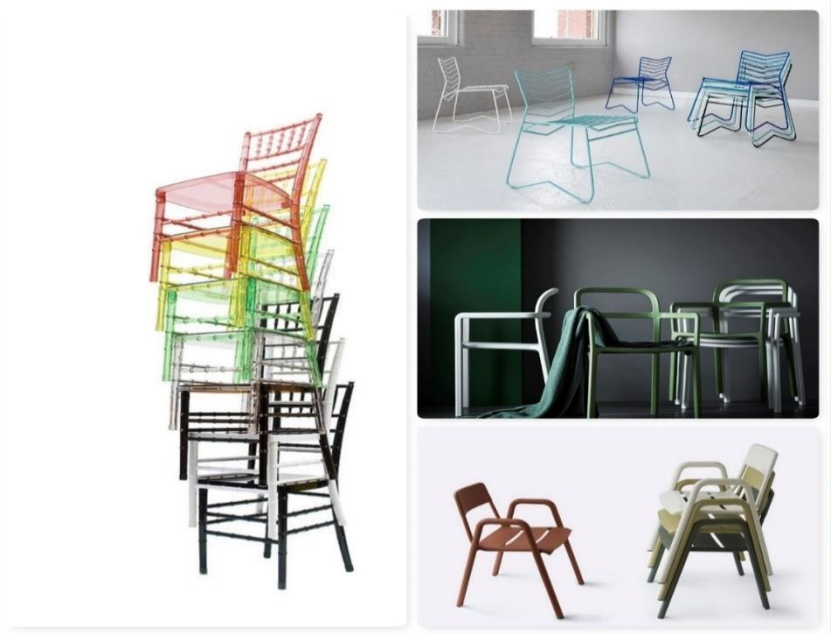

Figure 3 Chairs stacked (source: collage from http://leibal.com/page/2/?s=folding , https://www.busyboo.com/ , https://www.ikea.com/gb/en/p/ypperlig-chair-with-armrests-in-outdoor-green-40346580/)

2.3 Current State of the Art of Foldable furniture

The common feature in a typical folding piece of furniture, is the ability to fold flat or to a smaller size, and be stored in a stack, in a row.

Even if restricted to the furniture industry, folding can be executed in quantitative ways, depending on materials, unions, and hinges. Folding also involves constraint movements of rigid parts that often require clearing space to avoid collision, hence decreasing the size or extent of furniture parts to acquire space can be salutary to folding. Nevertheless, the folding directions play an important role in fulfilling the properties of a functional collapsible piece of furniture.

Models with mechanical movement that have the ability to fold can be divided into categories such as, sliding/rolling, paper folding (origami), pop up designs, nesting, collapsing or flat packs, that eventually keep the stacking advantage.

Table with examples for each type of folding furniture:

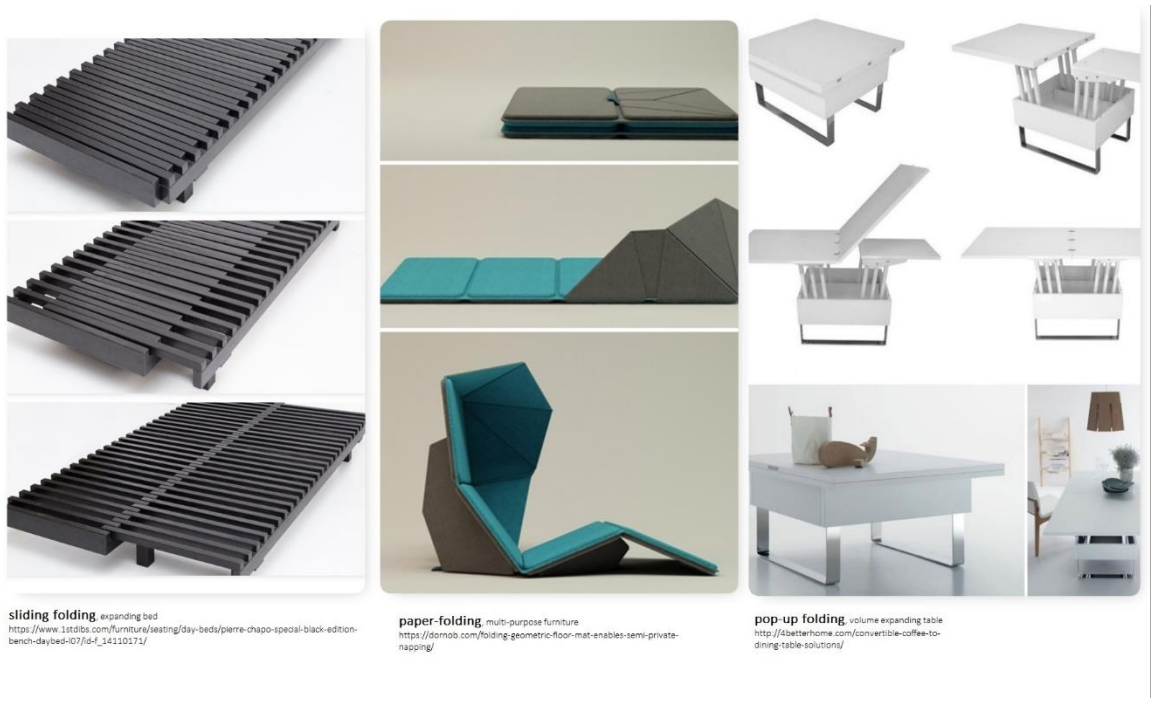

Table with:

***a**) Sliding folding, designed by Pierre Chapo (source: https://www.1stdibs.com/furniture/seating/day-beds/pierre-chapo-special-black-edition-bench-daybed-l07/id-f_14110171/)*

***b)** Paper-folding, designed by Chien-Hui Ko (source:https://dornob.com/folding-geometric-floor-mat-enables-semi-private-napping/)*

***c**) Pop-up folding furniture, designed by Alfio Padovan (source: https://www.arredatutto.com/en/furnishings/tables-and-coffee-tables/convertible-tables/imultifunzione-piccolo-p-33918.html)*

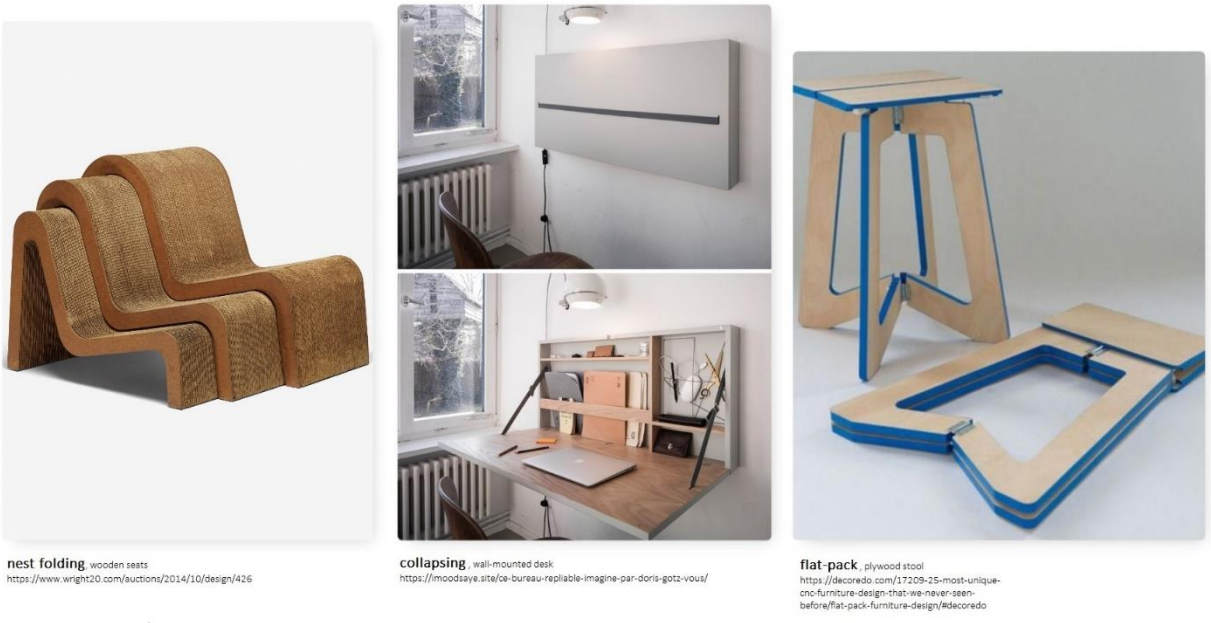

Table with:

d) *Nest-folding, designed by Frank Gehry (source :https://www.wright20.com/auctions/2014/10/design/426)*

e) *Collapsing, designed by Doris Götz (source:https://imoodsaye.site/ce-bureau-repliable-imagine-par-doris-gotz-vous/)*

f) *Flat-pack, (source: https://decoredo.com/17209-25-most-unique-cnc-furniture-design-that-we-never-seen-before/flat-pack-furniture-design/#decoredo)*

Qualitative research:

In order to gain an understanding of opinions, needs and current trends, qualitative data, through research questionnaire form, was gathered. It provides insights into the current users' needs, which could drive into developing ideas for potential quantitative analysis. Data collection method was, as mentioned, through a questionnaire, consisting of the following questions:

- Do you own folding pieces of furniture?
- Would you purchase folding furniture instead of static furniture?
- Do you need to adopt space-saving strategies in your house or office?
- Do you consider furniture portability as an important factor for selecting a furniture piece?
- What is the approximate area of your house or apartment?

Adults of all ages and from different scopes with regard to profession and lifestyle, answered the questionnaire. Through those questions it is possible to collect data regarding the necessity of folding furniture in combination with the area of a house and with the portability advantage. This way valuable information was gathered and provided insight on how important and practical choice it is for users to

have folding furniture, independently of their living space area. According to qualitative research over 70% of people own or used to own at least one piece of folding furniture, most commonly folding chairs, tables and stools. Definitely, it was expected to have equal relationship between the folding furniture need and people who live in small areas. Nevertheless, answers of 75% of people who live in a conventional house with adequate space, and 12,5% living in bigger areas, also expressed Although need for space-saving and portability. This percentage could lead to assumptions like having to live temporarily in a place and move to another, like students and businessmen often do. folding furniture satisfy such needs as they can easily be shipped and facilitate changes in living habits (for more information see the Appendix).

Quantitative research**:**

According to surveys undertaken by Folding Furniture Market 2019 Global Analysis and Global Demand Analysis and Opportunity Outlook 2024, analyzation and forecasts, suggest growth in folding furniture market. Market penetration of folding furniture can be attributed to the increasing number of smaller houses in the popular cities across the globe. Thus, the necessity of saving space for domestic purposes is of paramount importance. Foldable furniture is able to provide comfort way of living along with effectiveness of space-saving. Folding furniture market is emerging in key regions of Asia as well as Europe and America. Asia has the lion's share of the total generating revenues in 2016 across the globe referring to growth in population and smaller living areas (Bizwit Research, 2019). North America region is also anticipated to exhibit higher growth rate over the forecast period 2018-2025, due to increase in demand for low maintenance interior products, is driving the growth of the market in North America region. European region collapsible furniture designed by Europe's finest interior designers is gaining fame across the globe which is also referred as Space Savor. In rest of the world, Middle East & Brazil are expected to contribute significantly during the forecast period, mainly due to lack of space, changing lifestyle, and development of the hotels (Bizwit Research, 2019).

Moreover, through research reports by Folding Furniture Market 2019 Global Analysis, Growth, Trends and Opportunities, forecasts until 2025, a continuous growth in the market.

Reports on Folding Furniture Market provides an in-depth analysis of all market dynamics, including drivers and restraints, thus trends and opportunities. Important factors such us company, key regions, products, and end-user, supporting growth are also provided.

For the data information by region, company, type, and application, 2018 is considered as the base year, for the researchers of Market Watch that forecast until 2025.

Market research predicts growth figures between the forecast period from 2019 to 2023. In order to present an executive-level model of the market and its future perspectives, the report of Folding Furniture Market 2019 Global Analysis presents a clear segmentation based on many parameters. The factors that affect these segments are also discussed in detail in folding furniture market analysis reports.

Also, the Folding Furniture market 2019 Global Analysis report consists of a competitive study of the major Folding Furniture manufacturers, which will help to develop marketing strategies.

Whereas a market overview reveals an increased demand for space-saving, an increased demand for folding furniture is prominent among people residing in urban areas and metropolitan cities, too. Globally, the decreasing size of apartments is increasing the demand for space-saving furniture. There is also a high fragmentation of the market, as the global folding furniture market has a fragmented structure with the presence of regional and international vendors, which is one of the major factors that are expected to restrict the growth of the market (Gutierrez, 2019)**.**

2.3.1 Identification of trends

Folding furniture is a necessity for modern living. Portability and space-saving are of high importance, due to the small space living.

As revealed in this research, most commonly seen folding pieces, cover every furniture category, whether it is a bed or a chair, a table, or a stool.

In general, there are pieces for every taste and style, minimal, overwhelming or loud designs, can be delivered in folding pieces.

It is most common to see folding chairs, stools and chairs everywhere, in dormitories, residents, restaurants, waiting rooms etc.

Furniture designs that offer the advantage of stacking are of high preference.

Also, flat-pack solves frequently many transportation issues. The most popular types of folding furniture also happen to be those of ease-to-assemble, ease-to-use and of low cost.

A popular piece of folding furniture is the wooden folding chair, which folds in a very simple sliding option, based on pivots and becomes flat by nesting the seat with the back support. (fig.4.1-4.2)

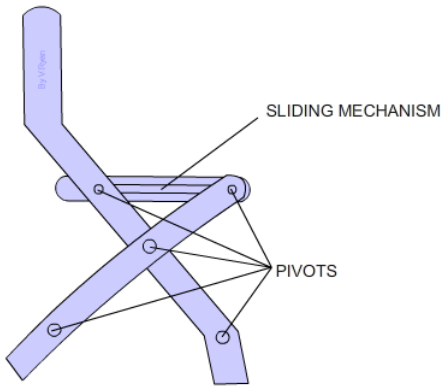

Figure 4.1, Sliding mechanism (source: *http://www.technologystudent.com/rmprep08/plchr1.html)*

Figure 4.2, Wooden folding chair by Winsome Wood (source: *https://www.amazon.com/Winsome-Wood-Folding-Chairs-Natural/dp/B004XYNE52*)

As we can see the sliding mechanism uses a railway in which the pivot or any other extruded part (tongue and groove setting) slides along. The railway integrated into the chair in many ways; either it is engraved as a cove (fig. 4.1) directly to the furniture part, or it is attached (fig.4.3) as an extra piece.

Figure 4.3, Folding chair with sliding mechanism attached, designed by Mathias Bruun Christensen (source: https://kadk.dk/en/project/folding-chair)

The rail could also be cut all the way through the part that support the mechanism (fig.5)

Figure 5, Folding chair with rail all the way cut through, designed by Lisa Hilland (source: http://furnitureandwoodshavings.blogspot.com/2014/04/lisa-hilland.html?spref=pi)

According to this type of sliding mechanisms plenty of other furniture is manufactured such as stools and tables. (fig.6.1-6.2)

Figure 6.1, Folding stool (source: https://thisisurbanmade.com/product/rhythm-stool/)

Figure 6.2, Folding table, designed by Mogens Koch (source: https://www.paletteandparlor.com/products/mogens-koch-folding-table)

Moving in a similar philosophy, there are folding furniture without railways that also tent to collapse in a closely way like the sliding mechanism outcome. In the following figure 7, there is a folding chair that becomes flat just by rotating pivots and a stop support at the desired height of the back part of the chair (fig.7).

Figure 7, Folding chair with slat cushion support, designed by Hans J. Wegner (source: https://wyeth.nyc/products/4968-001?utm_medium=Social&utm_source=Pinterest)

Moreover, when it comes to folding around pivots, multiple folding furniture evolved relying on material and fabrication differentiation. Using cloth or plastic-based fabrics, in combination with solid, durable shells brings out folding furniture with simple mechanisms.

An iconic example of such folding design is the director's chair.

The history of the Director's Chair (fig.8) dates back a long time ago, with unusual origins for what is considered a simple piece of furniture.

The director chair design goes back to the coffer-makers chairs of the 15th century, eventually to the Roman Curule chair. It is remarkable to think this simple, recognizable design could, in fact, date back as far as the Romans.

The modern American style Director's Chairs were introduced by the Gold Medal Camp Furniture Company in 1892. The company has been producing these directors' chairs for 122 years.

Figure 8, Director's chair, designed by Felipe Hidalgo (source: https://www.cb2.com/curator-white-cowhide-chair/s431266)

Directors adopted the design because they are easy to fold and transport when they are needed on a set for a location. The first appearance of this chair was at the end of 19th century during exhibition conference in Chicago. During the exhibition this design was awarded as an excellent piece of casual furniture.

The most recognizable design today is the lightweight armchair that folds side-to-side with a scissor action, using a canvas or similar strong fabric for back and seat. This design also has roots in the Renaissance era.

In the 19th Century, American directors began using the folding design on set, for its advantage of portability, giving the chair its modern name and establishing the design into modern furniture culture.

The construction of the Director's Chair seems simple in its design but cannot be overlooked for the importance of its construction. The most important consideration when building a Director's Chair are its joints. The chair is built with relatively slim timber sections which is subject to considerable stresses in daily use. It's the users' weight that makes the chair work, as the body pulls the canvas seat taut, which makes the chair stable.

The mortice and tenon joints must be accurately cut and fit tightly so that when glue is applied to form a strong bond. In its simplest form, the tenon tongue is cut to fit the mortice hole. If a joint is cut and glued correctly, it can be stronger than the timber from which it is constructed.

According to such a combination of materials and folding mechanisms, also debuted various pieces of furniture.

Having durable framing out of wood, plastic, nickel, or aluminum, in collaboration with fabric properties resulted in folding chairs, deckchairs, stools or even beds (fig.9.1-9.2).

Figure 9.1, Deckchair, designed by Jan Kurtz (source: https://www.design-bestseller.de/jan-kurtz-maxx-liegestuhl-ohne-fussteil.html?sku=900638)

Figure 9.2, Folding stool, designed by Östen Kristiansson (source: https://www.bukowskis.com/sv/lots/727891-pall-taburett-modell-203-uno-och-osten-kristiansson-luxus-vittsjo-1900-talets-andra-halft)

Another way in folding is the actual folding like paper (in cases paper is the structure's base material) (fig. 10).

Figure 10 , Paper-folding stool, designed for Doppelganger Outdoor (source: http://designmadeinjapan.com/magazine/a-book-that-transforms-into-a-stool-in-an-instant/)

Paper folding or origami folding furniture either as it concerns the optical or practical function, are similar to folding a piece of paper and similar to an origami piece of art. Due to this way of folding, furniture folds into flat-pack; they are commonly made of wood, plywood, or hard cardboards.

According to the design and the basic material, paper folding can be through various ways such us using hinges and pivots (fig.12).

Paper folding (Demaine, O'Rourke, 2007, Jackson 2011), origami (McArthur, Lang 2013), is perhaps the most popular way of folding. Paper folding origami, in general, allows folding and sculpting of a piece of paper to form a 2D or 3D shape. In most cases, the folds are straight, but 3D shape creation via curved folding has been studied, too. Origami designs can lead to fascinating 3D shapes that are more free form than the kinds of furniture objects dealt with in this paper. The design objective in this domain can be a difficult inverse problem; seeking a crease pattern on a piece of paper and a folding sequence that results in a target shape (fig.11.1-11.2).

Figure 11.1, Origami folding chair, images via Dornob (source*: https://weburbanist.com/2010/05/20/sit-on-it-15-more-marvelously-modern-chair-designs/*)

Figure 11.2, Origami folding table, image via Busyboo.com (source: https://www.busyboo.com/2011/08/11/origami-folding-table/)

Speaking of the product's origami inspiration:

"It was inspiring that you could take something cheap and ubiquitous and fold it into something amazing" (Kordos, 2014).

They satisfy the ease-to-use need, the sustainability and durability of a solid, strong structure and they are easily shipped.

In the same category are considered to be folding furniture with no hinges or unions, separate pieces, that connect either through nesting to each other or through tongue and groove (fig. 13.1-13.2- 13.3).

Figure 13.1, Compact dining set, designed for Norwegian Igland Design (source: https://www.busyboo.com/2009/04/22/mealbox-table/)

Figure 13.2, Nesting through tongue and groove folding deckchair (source: https://www.busyboo.com/2017/06/15/modern-lounge-chair-spyndi/)

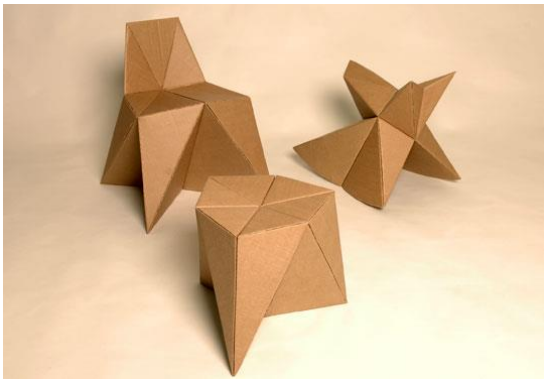

Figure 13.3, Cardboard folding furniture joining with tongue and groove, designed by Nicola Enrico Stäubli, (source: https://inhabitat.com/foldschool-diy-foldup-cardboard-furniture-for-kids/foldschool-9-cardboard-furniture-diy-furniture-kids-furniture/)

Nevertheless, a popular trend in folding furniture is the collapse with pop-up mechanisms. A pop-up mechanism usually works in parallel pairs used for lifting the top part of a piece of furniture, which has a pair of cantilever arms joined together by an upper oblong member and a lower oblong member, both upper oblong member and lower oblong member being parallel relative to each other, each being rotational attached to opposite ends of said pair of cantilever arms (fig. 14.1-14.2). In pop-up design, it is common to adjust hydraulic extension hardware hinges according to the function of the furniture.

Figure 14.1, Folding table with pop-up mechanism, designed by Steve Silver (source: https://www.homedepot.com/p/Steve-Silver-Crestline-Cherry-Lift-Top-Cocktail-Table-CL200CL/303815865)

Figure 14.2. Hydraulic mechanism (source: https://www.solidrop.net/product/furniture-design-hydraulic-table-lifting-mechanism-spring-assist-pop-up-coffee-table-mechanism-table-top-swing-up.html)

Design pop-up paper architectures where both folding and cutting are allowed, can occasionally resembles patch shrinkage work. In-place folding of the same scaffolds, require hinge insertion. In all cases, movements of the foldable patch are predictable by the scaffold types. Recent work by Ruiz Jr (2014) allows more pop-up styles, while can convert a given 3D shape into a multi-style pop-up design.

The goal is to approximate the 3D shape, using base and foldable patches, leading to a pop-up design. In contrast to paper folding problems, including pop-up designs, folding is the form of design optimization, which finds ways of modifying an existing 3D shape to make it efficient paper folding piece.

Another category of folding furniture would be the total steel/aluminum framed furniture. Either like campers' folding table or the old metallic bed in storage, such kind of furniture is met in most of the households.

Figure 15, Folding chair made of aircraft-grade aluminium and weatherproof ballistic nylon, designed by John Stump, Sam Chesluk, Alexis Courson (source: https://www.indiegogo.com/projects/go-chair-the-bottle-sized-portable-chair#/)

Camping type folding furniture is designed to boost portability through low weight and minimum folding volume. Typical camping type furniture can be seen in Figure 15.

As in every type of folding furniture, such gear has some common features and constraints. Most of the camping chairs have legs made from aluminum due to its durability and low weight to strength ratio. Additional features such as water-resistant fabric for the seating are very common in such kind piece of furniture. The usual weight of these products is below 10 kg (Tsolaki, 2014).

Because designers' tools of digital art evolve and manufacturing methods constantly progress, all the categories of folding can be adjusted in one structure with successful functionality, whichever way is most proper for every case.

With such range in folding ways, categories for linkage and union have been developed, having options such as hinges, pivots or just joints, depending on the need as mentioned by examining the types of folding.

For each type of folding furniture piece, there are type options for the optical characteristics and the mechanisms.

Regarding the desired effects, solutions of mechanisms have been evolved, in order to end up with folding parts.

Processing a design project, joints were not considered as center pieces. They were of a base to build the pieces of the project.

According to the type of furniture, its materials, and its usage, certain ways of joinery have been developed. Joints are mainly selected according to their abilities such as strength, durability, and aesthetic satisfaction.

Regarding materials' characteristics, timber joinery has been a prior choice. It provides craftsmen and machinery with precious precision and the ability of refinement constantly. Although the complexity of timber joints can occasionally challenge the skill of craftsmen, compromising attributes of tolerance application and assembly (Cormack, Sweet, 2018).

On the other hand, if craft is established to be automatically machined, joint complexity is decreased without affecting important attributes.

"It is not to consider human interaction excluded, but machine and human to be partners in the collaboration process" (Gramazio, Kohler and William, 2008).

Generally, wooden joints are considered to have advantages such as strength, flexibility, appearance, toughness, and more. Their characteristics derive from the properties of the materials involved and the joint purpose. In order to meet such differing requirements that are faced through folding furniture production, there are various union techniques.

For a great majority of folding furniture, in order to achieve collapse-ability, hinges and articulation are needed to result in a rigid construction with movable parts. To succeed with a folding piece, it is very common to use a traditional hinge mechanism, which typically allows a limited angle of rotation and has no more than one degree of freedom.

Hinges are out of metal, aluminum or plastic, and there are many types evolving, available of choice, according to the occasion.

There are kinds of hinges to choose, depending on the use and the desired model.

Typically hinges have no left or right side because when one turns them upside down, has the opposite movement. The majority of them can rotate at least 90 degrees. Below the main categories of hinges are presented:

- cabinet
- door
- furniture
- gate
- special (allowing more complicated movement than axial rotation)
- shutter
- window.

Hinges can be mounted with screw, nail, or welding. Most common hinges are those that can be screwed.

Further details of specific hinges are listed herein:

- Butt hinges are very common, and they feature two rectangular pieces of metal with holes (for the screws). Butt hinges are most commonly used on doors, panels, etc.
- T hinges are formed in a shaped like the letter T and are commonly used on front doors, chests and gates. T hinges come in many different styles and materials. In general T Hinges comprised of one narrow leaf and one wider leaf. Gate hinges are a shorter hinge with longer leaves commonly used on fencing. Gate hinges are consisted of two parts, an L shaped screw and a horizontal metal part. The L shaped screw on the long part of the L has grooves and

goes in the wall/wood frame, on the short part of the L goes the metal part, and it functions like a pin. This type of hinge is appropriate for fences & gates.

- Heavy-duty hinges are made of various hinge styles used in heavy-duty applications. Soss hinge is named after the inventor. This hinge is completely hidden. Because of that it is a bit hard to install, but it can bear a dissent amount of load.
- Piano/continuous hinge, also known as continuous hinge, it's a long metal sheet that runs the entire length of a door. Its function is similar to butt-hinge. Piano hinges are manufactured with or without holes. Such kind of hinges come in various thicknesses, pin diameters, and lengths.

Table of hinges' types (fig.16):

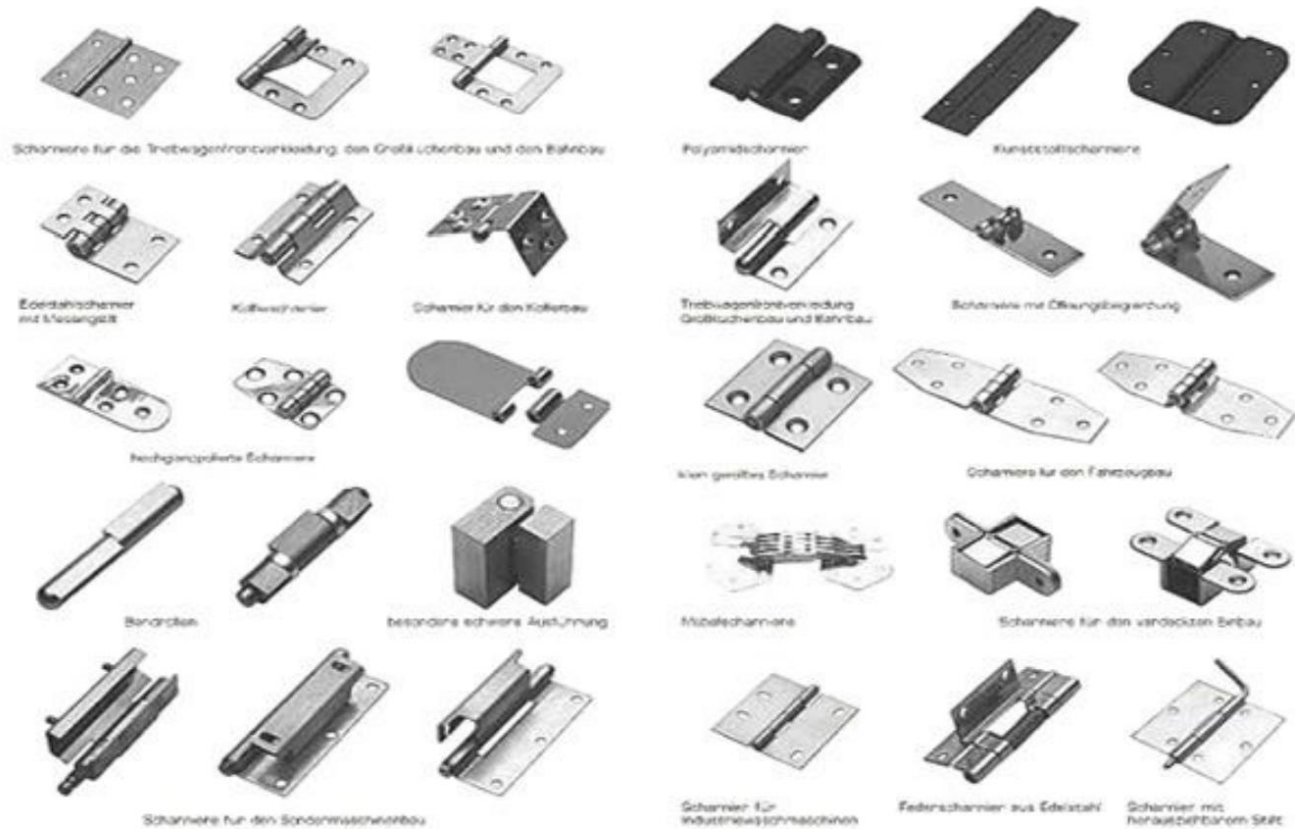

Figure 16, Hinges, image table via IHU repository (source: https://repository.ihu.edu.gr/xmlui/bitstream/handle/11544/15868/Faethon%20Sliomis%20-%20Vandoros%20Dissertation.pdf?sequence=1)

Articulation

Articulation is the ability of parts to be moved freely one of each other in a safe and easy manner without excessive friction. Articulations are commonly called "joints" coming in various shapes and types. "They are inspired by nature and mort of theme by human joints" (Vandoros, 2017)., Rigid body has six degrees of freedom, which refer to free movement in the three-dimensional space. Specifically, a rigid body can relocate its position within a Cartesian system (X, Y, Z) including changing in orientation through rotation around the three-perpendicular axis.). In next figure are the six degrees of freedom can be seen.

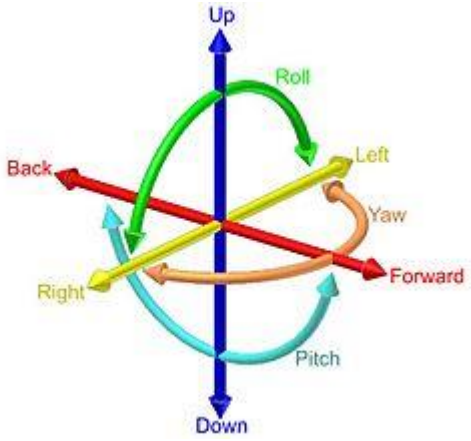

Figure 17, The six degrees of freedom of a rigid body

Joints are able to promote free movement in the six-degree movement system.

There are six types of joints:

- Plain joint with two degrees of freedom, allowing the movement on a certain plane and upwards away from this plane (figure 18, number 1).
- Pivot joint with one degree of freedom, allowing rotational movement around an axis (figure 18, number 2).
- The hinge joint allows radial movement of two parts that are moving around an axis. Its movement indicating one degree of freedom (figure 18, number 3).
- Condyloid joint allows the movement on an egg type of ball joint (figure 18, number 4).
- Saddle joint allows movement back and forth and up and down, but it does not allow rotation like ball and socket joint (figure 18, number 5).
- Ball and socket joint allow radial movement in any direction covering the full spectrum of six degrees of freedom (figure 18, number 6).

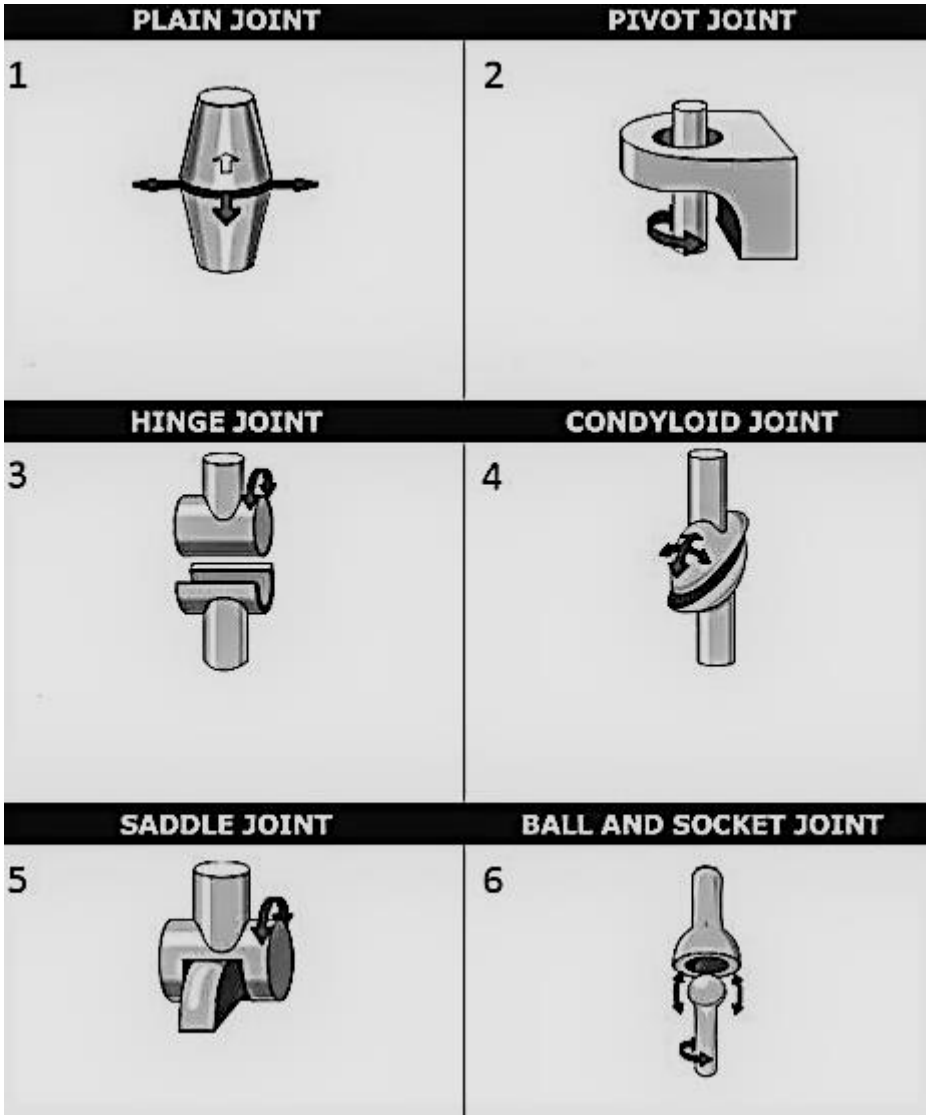

Figure 18, Types of joints (source: https://www.smartdraw.com/joints/examples/types-of-joints-diagram/)

Moreover, as multi-material molding develops, multi-material mechanisms that can combine compliant hinges are being created (fig. 19).

Figure 19, Folding cone with bistable compliant mechanism (source: http://www.research.usf.edu/dpl/content/data/PDF/16A031.pdf)

Multi-material molding offers the ability to create volute joints and durable links in a single piece. The motivation for a multi-configuration structure occurs in many applications such as space-saving furniture. The applications and structures often consist of several parts or mechanisms that may consist of links and switches which often have high costs of manufacture, assembly, and maintenance. Compliant mechanisms provide a transition point, while involving the flexibility of members to achieve all or some of their desired motion. A compliant mechanism transfers or transforms motion, force, and energy. Unlike rigid-link mechanisms, compliant mechanisms gain most of their mobility because of the deflection of flexible members rather than from movable joints. One advantage of compliant mechanisms is the potential for reduction in the total number of parts required to accomplish a specified task, in furniture industry, though, adjusting can be complexed. Such mechanisms can be manufactured from an injection-molding material and constructed out of one piece. The number of components required for a compliant mechanism is less than for a rigid mechanism. The reduction in part count may simplify manufacturing, reduce production and assembly time and cost. To further assist in the transition from paper to typical engineering materials, surrogate folds used in complaint mechanisms, create a localized reduction in stiffness, that must be utilized to function in place of a fold. Several methods can be utilized to achieve reduction in stiffness, like a change in geometry. For example, by thinning the material or reducing the cross-section at the location of the desired surrogate fold, one can create a localized reduction in stiffness. Another method used to reduce stiffness is changing material properties, as well as some advanced 3D printing techniques can vary the compliance of a material while maintaining the same cross-section. Material properties can be varied also by incorporating two materials into one-piece, thinner flexible piece and a thicker rigid material. The rigid material can be removed to create a localized reduction in stiffness. Moreover, changing stiffness can be accomplished by modifying the boundary conditions. Surrogate folds that achieve their motion through torsion are an example of this.

Compliant mechanisms, defined as flexible structures that elastically deform to produce a desired force or displacement, have recently been integrated into mechanical systems, to provide improved functionality, simpler manufacturing and greater reliability (Delimont, 2014).

The benefits of fold-able furniture are spread widely, with regards to fabrication, packaging, and use. Those topics are presented below.

Fabrication

Acknowledging the machinery capabilities of the production and the availability of particular digitally-driven fabrication equipment gives the designers the advantage to design specifically for the capabilities of those machines. Having this advantage, designers can calculate the most proper design with the best-suited material. In order to fabricate scaled or in some cases even physical models (fig. 19) using laser-cut, when digital modeling uses thickened surfaces occurs the need of very thin material such as balsa wood of thin MDF sheets, aluminum or steel sheets to end up with functional results. Sheets of material can be easily stacked over another, making transportation much easier (Vandoros, 2017). Small scale structures like a stool allow usage of parts laser cut as single pieces, whereas larger structures need further breaking down into shorter pieces

Furthermore, for mass production of organic shapes, materials such as polystyrene, nylon, polypropylene, polythene, and polyethylene can be used in a process called injection molding.

Figure 20, Laser cut stool by MDF, designed by Saori SHINYAMA (source: https://www.instructables.com/id/HARISEN-STOOL/)

These plastics are thermoplastics which means when they are heated and pressured in a mold, they can be formed into different shapes and colours.

Consequently, designers are becoming even more directly involved in the fabrication processes, as they create all the necessary information that is going to be translated by fabricators, directly into control data that drives digital fabrication equipment (Kovaleric, 2008).

Packaging

The flat-pack approach not only lowers the cost of furniture, but the slim boxes make it easier to shop and ship huge pieces (Cunningham, 2017).Having the advantage of folding into flat union or separate pieces, folding furniture offers the asset of scaled-down packaging, which makes it easy to be transported.

Packaging approach must fulfill three main objectives:

- The evident need for packaging. From this point of view, packaging must be efficient in terms of consuming the least void space. A cleverly designed package increase productivity by boosting storage capacity in the logistics supply chain. In addition, an easy to handle durable and safe package improving storage capacity and thus maximizing profit.
- Protecting the inside and outside environment. External parameters such as humidity, temperature or harsh environment may deteriorate the product. For that reason, a well though packaging design protects potential damaging factors (Yi-Wei Liu, 2007).
- Packaging also is the vessel that delivering the emotional message of buying the product. For that reason, packaging must be designed accordingly in order to positively influence purchasing decisions. Marketing importance of packaging is well described by Pathak (2014).

On the view of the whole piece of furniture, hidden in a flat pack package, consumers feel relief and satisfaction as the product of their choice can be easily transferred and stored at any time.

When one focuses on the product quality, needs a plain product packaging assembly that enhances the concentration in the main aspect of the product (Rpadmin, 2017). However, packaging is not important only in terms of increasing market share through brand loyalty. Packaging is important in delivering safety (Lamperti, Escher, 2007) and convenience (Jiménez-Guerrero, 2015) at the same time.

Furthermore, there is a constant development of innovative packaging design tools and solutions based on scientific insight into end consumer and marketing requirements, and state of the art in the packaging design discipline. For this reason, it is supported that the interaction between the package and the physical environment (e.g. temperature, humidity, and pressure) may result in changes in the package performance and its lifecycle (Morris, 2017).

Going back at the folding furniture packaging nevertheless, first appearance of flat packing in furniture was 50 years ago when Gillis Lundgren a Swedish furniture designer had to solve the problem of transportation of large table via vehicle. The need for a continuous way of transport was the initiative for an idea of furniture that could be manufactured in a kit form. This initiative was the spark of a new delivery approach regarding furniture (Rpadmin, 2017).

Lundgren's initiative changes the way of thinking in product packing. The product was not in the final form, but it was disassembled packed as tight as possible. From this idea, a need for clever flat-pack design was generated to take into consideration space limitations and was the precursor of ergonomics of modern flat packaging solutions (Rpadmin, 2017). Flat packing has also changed the way of thinking in logistics supply chain by introducing new ideas in production management. Specifically, flat packing gave the opportunity for maximizing production rates by creating an end product of flat packages ready to store in the logistics depot. Thus, production shifted from on-demand style to constant.

Remarkable progress was also made in automated packing. This method comes in different shapes and sizes with respect to given needs. Through automated packaging productivity increased since it became so flexible. Now this method of packaging became a part of the manufacturing process and is giving innovative packaging solutions by saving time and labor cost.

Use

Almost everyone knows by hurt how to use a piece of foldable furniture. The level of flexibility and versatility is so high that foldable furniture is dominating in everyday life.

Folding furniture is an ideal option for limited spaces. When not need to be operational, folding furniture takes very little space. But one does not necessarily need to live in a small apartment to adopt folding furniture (Bizwit Research, 2019). The advantages of folding furniture, eventually, are realized when using. Either the assembly is easy or in some cases more complexed, the final folding product when ready to use, fulfills its purpose. Having multiple functions of a piece of furniture, while saving space, in one or two moves to fold or transform, satisfies daily needs for each lifestyle.

Depending on the piece of furniture and its function, with a single move, one can either store the piece or use it. By sliding out a drawer-bed, by "clicking" a pop-up table or just unfold a folding chair makes daily living easier and comfortable.

Compactness, mobility, and variability are some of the advantages of folding furniture. They can be stacked away within minutes and occupy a lot less space. From folding beds to folding chairs and tables, furniture has the unique ability to transform rooms into convertible ones via some moves. In some cases, there is also the advantage of modifying a piece of furniture according to the need, such as shown in the following picture (fig.22).

When folding furniture is not in use, they can be stored as they are usually light in weight and transportable.

Figure 22, Transforming seating (source: https://resourcefurniture.com/product/scala-zero/)

According to the mechanism and the way of folding, it depends on the ease of assembling and using.

Assembling can be complex due to the need of applying properly the mechanisms or hinges, and there can be constraints according to the type of folding, regarding the grades of freedom in moving directions or rotation. Once the assembling is done, a functional folding piece of furniture derives with all its advantages while using. When folding is through sliding, there is the direction of sliding parts to take into consideration while putting into place to use. Other than that, the sliding parts are used like drawers. When folding is with pop-up mechanism, all it takes is applying certain pressure at the folding part and either let it pop out at a certain position or in some cases rotate it and lift it.

When it comes to paper folding all it takes is folding and unfolding. While folding furniture is useful as it is easy to move and can be kept aside when not in use, a variety in folding and portable furniture can be found across the market. Households, Companies, travelers can use folding furniture in many ways.

In a household, there are multiple needs where a folding piece of furniture can be the best of solutions. Folding chairs stored in case of many guests, possible with a folding table that can get wider. There are, also, several types of folding beds like futons, guest beds, and hideaway beds. Besides such pieces, there are folding furniture used to assist in any daily activity, like folding ladders, folding desks, even folding closets. In any case, under any circumstances, folding furniture exist in any household, saves space and satisfy each user's need.

When it comes to organizations, space should be used wisely, whether they have large areas or limited available spaces. When furnishing workplaces, folding furniture can prove to be very effective for all types of spaces (Smith, 2015).

As it was said before, folding types of furniture items are portable and occupy very little space when not in use. Hence, for small companies folding furniture can be an ideal investment.

Folding furniture for workplaces such as companies can use folding tables and chairs to equip their spaces. Wooden or metal folding tables with chairs in several finishes, shapes and colors are available on the market. These types of furniture pieces can help in creating a modern, functional furnished work environment. Moreover, collapsible cupboards, boxes, and creative storage utilities are available, to occupy less space and fulfil requirements of businesses.

Folding furniture can be used in company waiting rooms as well. It is light in weight and easy to move. Thus, while cleaning or rearranging the décor, this type of furniture pieces is easy to handle (Smith, 2015).

Nevertheless, folding furniture can be used for several conferences while organizations need designated conference or meeting spaces, where they can conduct meetings, training, team discussions, etc. For creating and furnishing these places, companies can use folding furniture. Folding tables in varied shapes along with chairs can be used to furnish such conference spaces.

Companies with free outdoor spaces can use those areas for meeting or relaxing purposes. A variety of wood or metal folding tables and chairs can create elegant patio or picnic furniture in company outdoor areas.

Regarding the portability that folding furniture provide, use while traveling cannot be missed.

There are many products of each type of furniture (chairs, stools, closets, tables, beds) designed exclusively for camping or traveling in general.

According to the Eurostat report “Eurostat regional yearbook 2012” there is a significant percentage of traveling population that avoids conventional way of tourism and shifting towards alternative tourism consisting mainly of camping.This trend of non-conventional tourism boosted during the years 2007-2010 when the economic crisis was at the peak (Tsolaki, 2014).

Campers need collapsible furniture, light-weighted, with high durability and with proper comfort. Such kind of furniture can be transferred easily and occupy minimum space when are not in use, while this type of furniture is less expensive and can be cost-effective in the long run. In addition, the furniture market is flooded with folding furniture products that can cover most of the needs of modern way of leaving.

DIY movement

The Do it Yourself movement (or DIY) currently keeps spreading and emerging across the globe. It mainly comprises different ideas and practices of what is called self-made-culture. DIY’s evolution is not stopping and now in the context of many aspects of everyday life from home improvement to music and software engineering. DIY has already become a culture that is spreading everywhere. While in the home-improvement the DIY-culture has a long history, it became popular in other fields of everyday culture, not until the last few years (fig.23). Today many people like to make their furniture by themselves and often those self-made products are as well offered for sale.

Home improvement such as renovating and remodeling one’s home is the largest segment in the DIY furniture market. The global DIY market is growing, and this growth is mainly supported by the media presence, through television or the online information in the form of video, websites or social media. Online platforms like YouTube, Pinterest and other blogs are sources of DIY projects, tutorials and how-to-do videos. Every individual can share his project, give feedback or receive a review. Especially big furniture retail stores such as IKEA focusing entirely on DIY movement in an effort to maximize

profitability by lowering production, packaging and distribution costs. In addition, DIY culture promotes self-motivation and feeling of achievement for the customer. These are the main drivers for furniture industry to invest more in DIY movement.

The most popular DIY furniture projects are various types of tables (dining, coffee, side tables), shelves, chairs and benches, storage cabins, beds, sofas, and desks.

In general, DIY consumers have a desire to be creative and active, and they perceive handicrafts as a form of relaxation and enjoyment. They have a need to personalize, help the environment and save money at the same time. The DIY consumer is here and growing, nevertheless, DIYers are hard to profile because they aren't confined to standard consumer parameters like age, geographic location or income earnings (Williams, 2015) Many people today prefer to learn how to make something on their own, reading bibliography or by researching the internet, rather than buying it ready-made. Also, more and more people want to repair or convert their old or damaged items, rather than throw them away, either due to emotional attachment or limited affordance.

Today, despite the negative facts that the economic crisis has imposed on our society, has also triggered a need for creativity, as many users have changed their consumer habits and found alternatives which are more economical, nevertheless, not lacking in quality and functionality.

“So, through the self-made-culture, building a furniture piece on one’s own, can save money can get exactly what is wanted can be green can be a healthy family activity, providing fun and rewarding” (Higgins, 2012).

As DIY trend merged in the furniture field, in collaboration with free access in more technical information, the potential in making folding furniture became popular, too.

Figure 23, Brief history of DIY, image via cupagroup (source: https://www.mystonetack.com/en/history-do-it-yourself/)

With some basic tools, many sales points, or already existing pieces of materials in a household, tutorial methods and inspiration, one can build any desired piece of furniture.

This trend also raised since the increase of environmental awareness and awareness of ecological problems (Chopteridou, 2018). So, there are everywhere available sources in order to get ideas on how to recycle materials and turn them into useful and aesthetically pleasing pieces of furniture, too.

2.4 Future of Folding furniture

Mechanics, physics, architecture achievements and design, numerous information sources, DIY culture, material market, and manufacturing flexibility make it doable for every customer to acquire a multi-usage construction of folding furniture.

A trend in the furniture market that is becoming increasingly popular is the so-called open-source furniture, where one can download or make the design of a piece of furniture and send it to a CNC machine (mill that cuts wood from a digital file). With the pieces cut, one just assembles the desired folding furniture. Opendesk, is one of the current open-source furniture platforms, brings together about 30 pieces of furniture available for download. There the user can download a project and cut the furniture in a FabLab or personal workshop or use the site to connect with a joiner who makes the cuts. Open source furniture has emerged following this trend, boosted by the do-it-yourself culture. By connecting designers, local producers, and customers with eliminating intermediaries, export and import costs, logistics and distribution costs are also minimized. Despite the high numbers of downloads and that furniture is produced this way around the world, open-source is still something very new and developing (Souza, 2019)

Multimedia technologies, material abilities, and progressive stimulation lead to numerous possibilities in the future of folding furniture. Transforming and modularity in furniture, promises a wide array of applications. A theory has been developed in which transformation encapsulated in a set of transformation principles and facilitators. These form a basis from which a transformational design methodology is developed. In the current progression of the transformation design theory, describing a renewed approach for generating and analysing system usage scenarios, objectives, customer needs, and capabilities all it takes is inspiration and practicality in order to satisfy every possible need in furniture.

Combining means enables the choice of a great differentiation in customizing every piece of furniture according to each one’s need.

The design of transformable spaces is not a novel idea since examples exist from the ancient times. Its widespread application though was rendered impossible mainly due to lack of the technology required for an easy-to-use and easy-to-maintain kinetic structure. In recent years, many technological breakthroughs have opened the way towards viable solutions for transformable building elements within structures.

Characteristics such as aesthetics and modification capabilities keep growing high on demands and occur with high complexity and restrains. Generally, modular interior design has become very popular, and one of the biggest trends when it comes to interior designing. Modular furniture is highly flexible and efficient and has lots of potentials while this field continuously develops. Modular constructions are made from pieces designed to fit together in a number of different ways like the following example (fig.24).

Figure 24, Smart kid furniture (source: https://www.busyboo.com/2010/07/11/kids-furniture-smart/)

There is the capability to easily put furniture together using different pieces available to get the desired result. This allows to rearrange furniture whenever, without any hassle. In most cases, designers also provide the end-user with design solutions for the best possible settlement as one can easily hide cables and connectors throughout the walls of modular furniture. This type of furniture is available in a range of sizes, shapes, and colors, providing the choice of the furniture pieces that suit better the needs (fig.25). Its other great feature is that modular designs commonly provide the choice of extra pieces that are adjustable. There are furniture pieces available that will ensure comfort and give wanted look for each household.

Figure 25, Futuristic modular construction, designed by Roland Landsberg (source: http://inventorcentre.net/storage/1515-futuristic-interior-boxetti-collection-rolands-landsbergs.html)

Folding furniture evolved into transforming furniture with a great range of constructions for every type and category of furniture.

“A Transformation Principle is a generalized directive to bring about a certain type of mechanical transformation. A transformation principle is a guideline that, when embodied, singly creates a transformation” (Singh, 2007).

Transforming furniture frequently combine up to two kinds of furniture, ending up to smart solutions for every space and every affordability state(fig.26).

Figure 26, Nesting pieces of furniture for multi-use (source: http://www.architectureartdesigns.com/15-exceptional-modular-furniture-designs-which-are-worth-having/)

Transforming furniture derived from the ability to combine different types of folding pieces, material capabilities, and mechanic evolution.

The examples are numerous and cover nearly every contingency.

Structures can host completed rooms (fig. 27), working, or living spaces.

Figure 27, Modular room, designed by Oda Architecture (source: https://www.busyboo.com/2010/05/27/small-spaces-oda/)

Foldability offers the choice of including every necessary piece of furniture in one transforming piece.

Another technological achievement as heat forming material, with the great ability of bending, gives the advantage of elasticity, occurring with possible 3D printed folding furniture without traditional hinges or joints. Design using generative design software provides designers the ability to optimize where needed, to lend support and lose heft(fig.28). 3D print also gives the advantage of generating models by emulating organic structures, found in nature.

“Previously designers were inspired by ‘organic’ as a style, but what is completely new is that designers are now inspired by the organic process itself, and how to emulate it” (Jouin, 2019).

Figure 28, The TAMU chair, 3D printed folding chair, designed by Patrick Jouin (source: https://www.curbed.com/2019/4/17/18411239/3d-printed-chair-patrick-jouin)

3 Case Studies

In order to analyse the design-to-production process of folding furniture and for better understanding, there are representative cases for some categories listed through this thesis. A classic model of folding furniture with railway and pivots, a more modern approach of folding with pivots that turns into flat-pack and an origami-inspired piece of furniture.

3.1 Selection and Design of Case Studies

The case of origami-inspired furniture, Origami, or paper folding furniture industry gave a new and innovative generation of furniture. The Cut and Fold, a Kickstarter furniture project by two Canadian architects, fuses plywood and papercraft, a great experiment that turned into a great idea for multiple applications. Through this project, Andrea Kordos and Tony Round used plywood and piano hinges to form minimalist furniture that's sculpted out of flat pieces of wood. One of their results is the papercraft-inspired Origami Chair, made from plywood and piano hinges, which folds flat and rests comfortably on a steel frame (fig.29).

Figure 29, Paper folding chair, the Cut and Fold chair, designed by Andrea Kordos and tony round (source:https://www.dwell.com/ARTICLE/ORIGAMI-INSPIRED-FURNITURE-YOU-CAN-FOLD-FLAT-031D9DCD)

A rounded piece made from CNC-milled plywood that has enough give to contour, to the person sitting down. The pieces are relatively easy to produce, while the ability to fold and carry reduces shipping costs.

The Cut and Fold chair project is worth studying regarding the origami folding methods, the geometrical guidelines, the constraints, and the most proper solutions.

Another iconic piece of furniture would be the folding stool by Roger Tallon (fig.30).

Figure 30, Folding stool, designed by Roger Tallon
(source:https://www.ozshop.design/vintage/xk2z1j93ylonvmj3dqrsmhxyvgilf2)

Roger Tallon's legacy is uniquely grand. His expansive creativity matched his enormous oeuvre. His work increased for the better and redefined daily life, responding to Tallon's desire to improve lives through design, romantically meant to relieve the pressure of a changing world. His works continue to receive recognition, found in major institutions including the Museum of Modern Art, New York, and Musée des Arts Décoratifs.

When observing closely at the stool, it is constructed of three main parts:

- The round seat (with a round hole, for hanging)
- One rectangular leg that fits into a squared-off U-shaped leg
- Squared-off U-shaped leg (made of three pieces of wood, or cut from a single sheet)

In figure below sketch (fig. 31) of a Roger Tallon Folding Chair is depicted. Current sketch gives a sense of how the stool is put together; it's folding and the flat-pack legs that fit together.

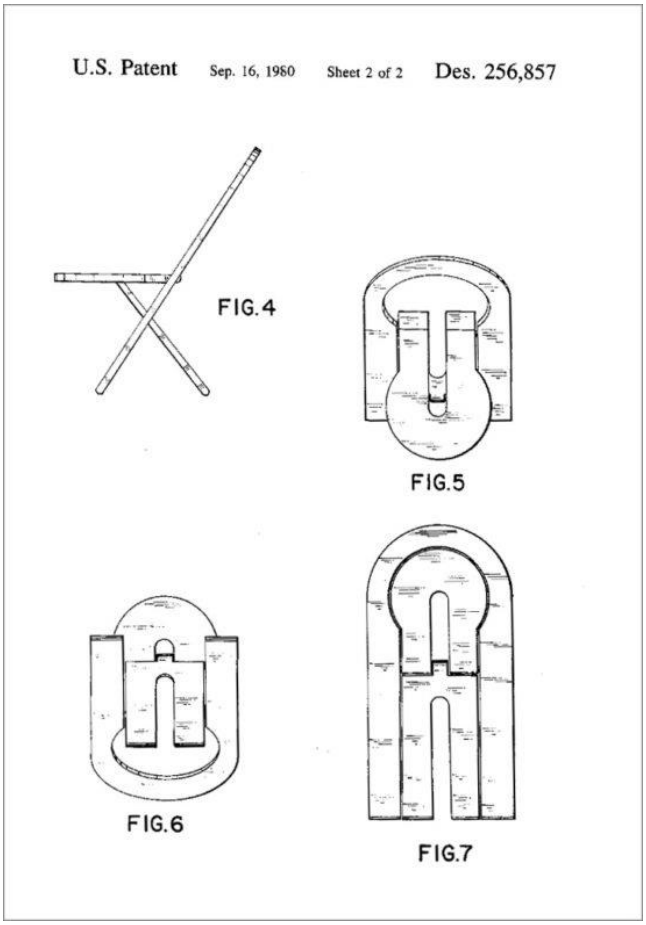

Figure 31, Plan of Roger Tallon folding stool (source: https://www.improvisedlife.com/2016/07/20/DECODING-TALLONS-ICONIC-HANGABLE-FOLDING-STOOLS-CHAIRS-DIY/)

In order to study another folding furniture category, such as folding into flat-pack, with nesting parts like puzzle pieces, there is the jolly folding chair (fig. 32) or sheet-seat, is optionally made from a single piece of wood laminate or bamboo. The production process is straightforward, generating almost no waste. The simplicity of the design allows for savings in workmanship, manufacturing costs, and energy consumption. The flat panel can be unfolded into the final chair position in a few steps, and folded back into the original 3/4-inch-thick sheet, facilitating stacking and bulk transportation (Keskin, 2011).

Figure 32, Jolly folding chair, designed by Valdenassi (source: https://mineknow.wordpress.com/tag/chair/)

3.2 Design to production workflow

The first step in the process of building prototypes is the design of the models.

The 3D models were created in Rhino, while in the case of the origami folding chair, the designs where handmade.

The stool had a clear planning and designing rules, clear shapes, and figures. The 2D model, the3D model and a rendered one follow at the table above (fig.33).

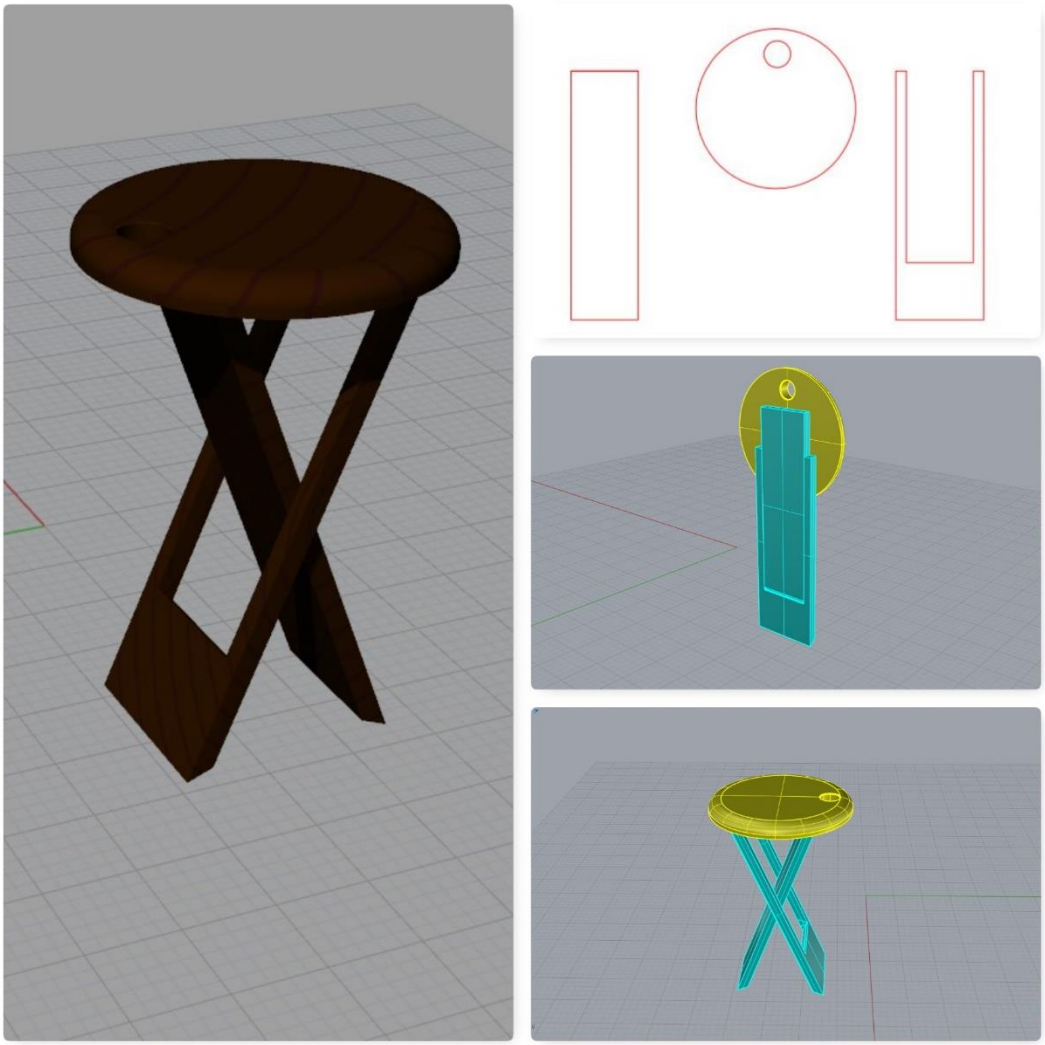

Figure 33, Designs for stool prototyping

While designing certain measurements had to be considered in order result with a stool whose parts fold and slip into each other properly. For the scaled model balsa wood was cut in laser cutter machine, where after cutting, followed the assembly of the pieces. Due to the thin sheet of balsa, there is no capability of engraving a railway.

The designing of the Jolly folding chair was also made in Rhino for the 3D model and AutoCAD for the 2D starting model. The designing process was subtractive, while there is a main figure where the smaller parts nest into, following similar shapes (fig.34).

Figure 34, Design of Jolly folding chair

For the origami folding chair, paper and pencil were used, for better understanding at the same time the way it would fold. The Cut and Fold chair is a hexagon shape, but in order to fold into a curved hexagon (the seat support), needed some experimentation. Either it would be composed of two identical mirrored pieces, or one single piece (fig.35).

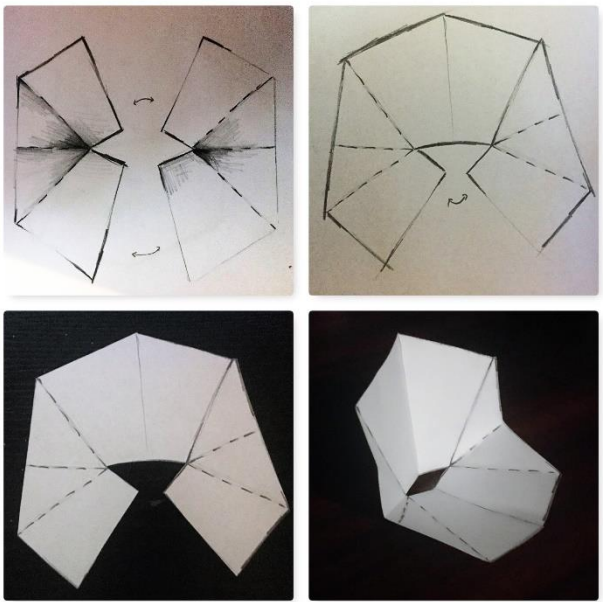

Figure 35, Design of Fold and Cut chair

3.3 Prototypes

After designing the models of the case studies, followed the prototyping.

For the Roger Tallon stool, balsa wood was used and cut in a laser cutting machine. The prototype was composed of three pieces (fig.36).

Figure 36, Balsa wood, pieces of stool

For joining the pieces, duct tape was used, as balsa wood was of four millimetres thickness and pivots could tear the wood apart. During assembling, the problem of the missing railway, where one leg slides into the other, came up. Other than this, the folding was successful, the closed stool was proper, and the open position stood evenly (fig.37).

Figure 37, Closed/open stool prototypes

The Jolly chair was also made of balsa wood, and the joining was made with duct tape, too. Three pieces were cut (fig.38).

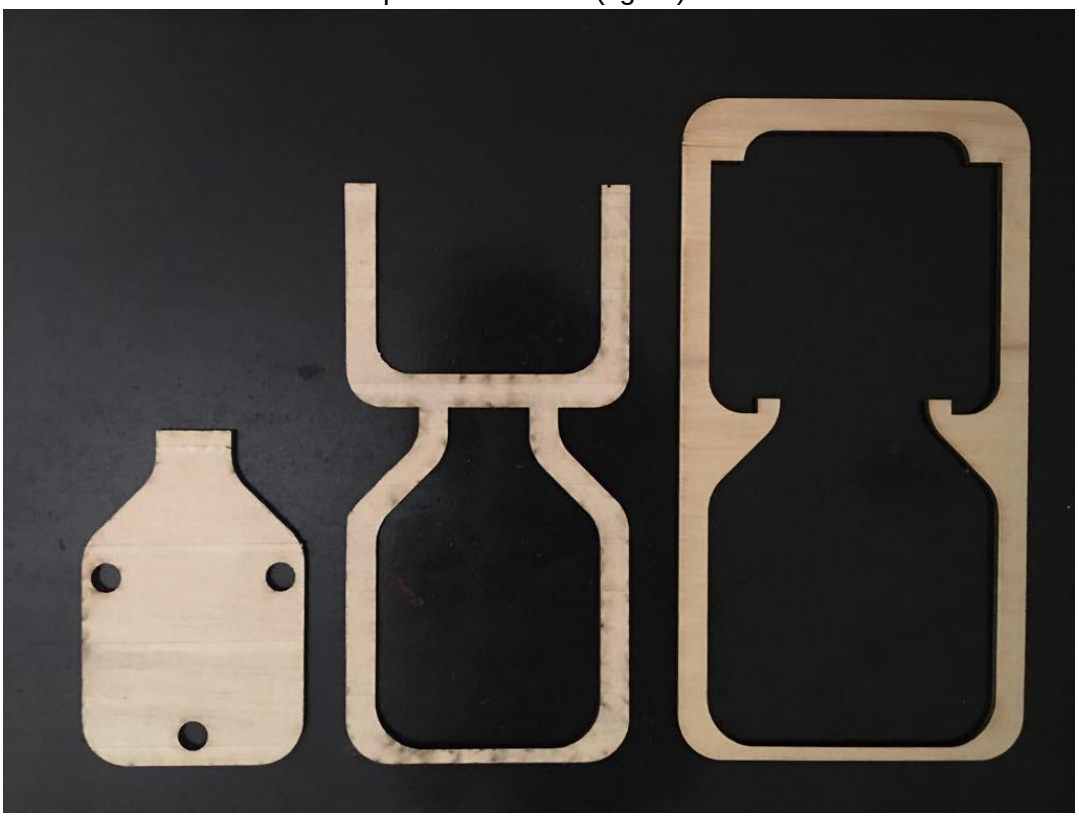

Figure 38, Balsa wood pieces of Jolly chair

The space left between the three parts was crucial for their adjustment, while to fit in like puzzle pieces into a flat pack and open properly to stand, needed accuracy. The final assembled prototype was functional, folding open, and closed (fig.39).

Figure 39, Closed/open Jolly chair prototype by laser-cut balsa wood

The Cut and Fold chair prototype was made by foam board, cut with Exacto knife, joined with duct tape and aluminum foil with plastic strokes were used for legs(fig.40.1-40.2). While the physical model is composed of eight separate pieces of wood and assembled with piano hinge, the one-piece prototype was quite a puzzle to make it functional.

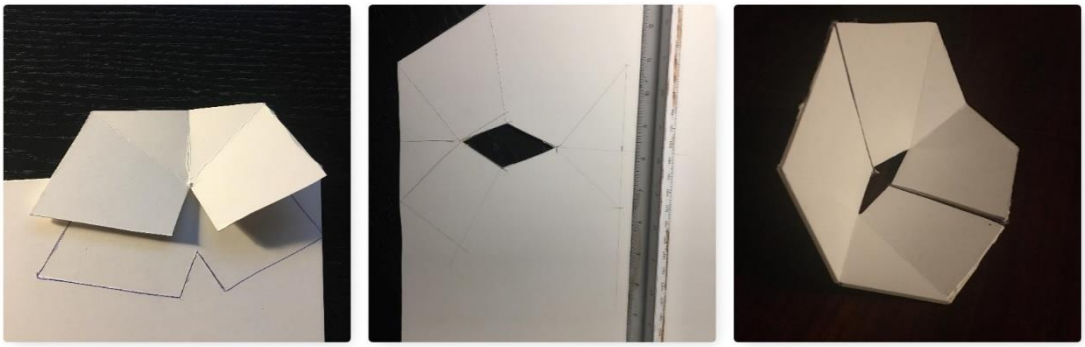

Figure 40.1, Foamboard designing, cutting and assembling prototype of Cut and fold chair

Figure 40.2, Cut and Fold chair prototype, by foamboard seat and aluminum foil legs

While there is a wide range of possibilities, one cannot underestimate the importance of physical (scale)models and prototypes, as they have the potential of revealing overlooked design flaws and verifying the digital models (Temmerman, 2014).

3.4 Findings

The steps outlined provide a systematic mode of obtaining knowledge regarding the design to production workflow. Obviously, the thickness of materials is important, in relation to each piece's way of folding, its joints and railways. Having this in mind, the designer engineer must take a step back and re-examine the big picture. According to the need, a designer has to examine the most proper materials, keeping in mind the mechanisms of folding that are going to be used. For example, having to succeed folding in the Cut and Fold chair case, provides the designer with many options of materials. This origami folding chair folds by using piano hinges, which makes it possible to choose thin material sheets either from wood, plastic or metal. On the other hand, having to adjust mechanism with a certain volume, that intersects the pieces, needs further examination. For both Jolly chair and Tallon's stool, hinges and pivots intersect the folding parts, which lead to constraints regarding the thickness of materials to use.

Ideally, a product is able to fulfil customer's objectives and needs. Transformers may provide some new insight and solutions. The purpose of a transformational product is to be able to execute an objective requiring or dependent upon a certain state and then transform to a different state in order to fulfil a different objective. The designer should explore transformation when encountering the situation where different objectives requiring independent states are necessary to carry out the general scenario. Its implementation is left to the creativity and subjectivity of the design engineer.

4 Synopsis & Conclusions

4.1 Synopsis

Through this thesis, folding furniture design to production process was studied from different points of view, in order to obtain a thorough understanding of the subject matter. To begin with, it was necessary to study folding furniture history facts in order to record when, how, and why folding principles were adopted in furniture. Since bronze ages people generated the idea of folding furniture that until nowadays became present in every household or workspace.

Folding furniture developed and kept evolving according to users' needs. They cover every category of furniture (chairs, beds, tables etc) and customization alternatives. Folding furniture diverse according to the way of folding, the materials, the colours, and shapes. Research through thesis showed that the folding furniture market keeps growing, with demanding needs. Nevertheless, fabrication, packaging, and use of folding furniture evolved and met such market needs. From precedents to current trends in folding furniture, such products kept spreading and qualitative research resulted in the majority of people to own at least one folding piece of furniture.

For a better understanding of the design to production process, case studies were undertaken in order to build prototypes of three types of folding furniture (a classic stool, a flat-pack chair, a paper folding chair). Through this procedure, constraints and design problems occurred, that every designer has to re-examine and take into consideration while generating a design idea. Such restrictions can be either upon the ideal materials for each folding purpose, or upon the thickness of chosen materials, or regarding the joining way of the pieces of a folding furniture.

4.2 Conclusions

People's needs led them in solutions to make living easy to adjust in most space adequacy, therefore saving space, as researched, does not depend on downscaling but on smart ways of collapsing and transporting a piece of furniture. Folding principle is the most frequently met on furniture.

There are precedents of folding furniture that date back to the Bronze years. However, the modern lifestyle and the reduction of space of apartments in the cities have made this type of furniture a necessity for nearly every household. The benefit comes from their ability to change shape and facilitate new functionality; all within a single system. Research through this thesis led to conclusions regarding the needs of the market, the possibilities that furniture industry provides in production and the design development. Folding furniture market, nowadays, is quite demanding, as space-saving and portability are necessary for products' end-users. Being aware of what choices people have, regarding space-saving methods, the whole furniture industry must meet both need and taste. Folding is certainly an easy and straightforward process for transforming shape and an excellent starting point for creative design. This approach enables fast and easy achievement of three-dimensional shapes which clearly show better structural properties than traditional furniture.

Current trends in folding furniture can be categorized according to their folding way such as the sliding way of folding, the pop-up mechanical folding way, the paper folding parts of a piece of furniture, the nesting folding and the camping type of furniture which can be folded and fit into a single bag.

Gathering so many interesting properties from such a simple transformation inspired designers and gave solution to space-saving needs. Taking into consideration fabrication, packaging, and use, designers and manufacturers also developed and kept coming up with solutions for every spatial need. Material selection for durable results in combination with the advantage folding into a flat pack, to finally end up with a folding piece of furniture that transforms within a single move. According to the need, mechanisms also evolved to suit the best way into each type of folding piece. Either joints with one grade of freedom or more complexed hinges, turning pivots, tongue and groove methods of joining or hydraulic suspensions, folding efficiently can be achieved in many ways.

Through studying the folding furniture design and production process, it became clear that the folding furniture industry will be important for the coming decades. People use folding furniture for a long time ago until today, while space-saving and portability are necessary, for households, workspaces or traveling. Qualitative and quantitative research showed that users need the advantages of folding furniture with regards to storage, use, portability. Design ideas and production methods keep developing in order to meet every need and at same time to overcome possible constraints and complexed constructions. All categories of furniture can become transformable, guided by the folding principles. Solutions for packaging and easy shipping are also driven by the developing of folding furniture, which makes it even more convenient for the end-user to obtain each furniture piece. Folding ways, materials, joints, shapes, and colors can accommodate every need and taste, while the DIY culture makes it possible for the user to build a folding furniture piece of his favour.

The past and current state of the art of folding furniture has been studied, from precedents to contemporary trends. Folding furniture split into categories in relation to the type of furniture (chairs, beds, etc.), the way of folding, to materials and to the way of production.

As the need for saving space exists and keeps growing, the production of folding furniture evolves. The need for space-saving turned design of folding furniture into an essential sector of the furniture industry, with a demanding market. The aim is functional design that can satisfy end-users' needs, regarding many aspects such as the ease of assembly, the ease of use, the transportation, the modification or customization. After all the combination of parametric tools, new fabrication process based on numerical control and 3D printers brings architects and designers even closer to actual constructions of furniture. It is much faster to test the expediency of a design thanks to rapid prototyping. The design cycle is strongly accelerated. Provided the digital format is compatible with the full-scale fabrication process; architects and designers are directly editing working-drawings from the beginning. This emboldens them to have direct interactions with manufacturers. In this encouraging context for innovations in construction, it is worth to focus on aspects like the form-finding process related to folding and the behaviour as a structure of a folded shape.

Eventually through case studies, findings, regarding constraints and solutions, occurred and gave an insight on what a designer must take into consideration while generating a furniture model. Most importantly, there are constraints regarding the design, the way of folding according to the materials and the needed mechanism. Clearly a designer must have insight on material thickness and mechanism volume, in order to select the best solutions for each design. Nevertheless, a designer has to examine the direction in which a folding piece spreads and folds back into a flat pack. Also, according to material selection, in some cases, such as the Cut and Fold chair or the Director's Chair, a designer has to consider the users' weight, as for such furniture to be stable, weight brings the balance.

Aesthetics cannot be overlooked, especially with so many choices of materials, colours, and shapes, but in the folding furniture industry functionality is the main requirement. As Roger Tallon relevantly suggested "Beauty is the simple result of a well-made work. A form doesn't need to be beautiful, but good, good because it is logical, practical and does its job" ((Tallon, 1978).

4.3 Future work

Regarding future work, modularity in furniture would be studied through a more technical and engineering viewpoint. It is of great interest how technology, material characteristics and design knowledge can lead to functional solutions like modular pieces of furniture. A cross-disciplinary approach to folding furniture could also lead to a better understanding of reactions and functions, while it makes it possible to generate even more sustainable designs with modification properties. Research in the material science point of view is well established but new technologies such as 3D printing enhancing functional solutions of folding furniture by boosting productivity of more complicated designs. Reusable materials can also be a part of this activity. Plastic garbage can be used as raw material in 3D printing applications with a positive environmental impact at the same time. Last but not least improvements in structural analysis through sophisticated mathematical models can re-establish the folding furniture production by lowering production costs at the early stage of design of a new product.

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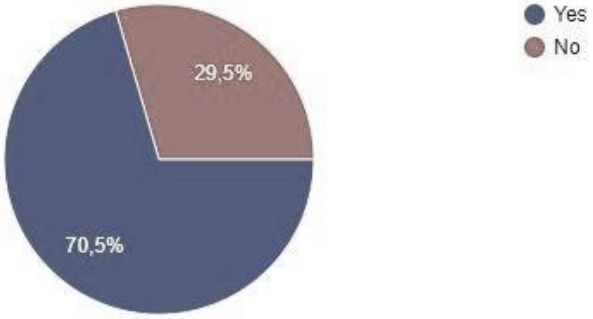
Appendix

Table of questionnaire

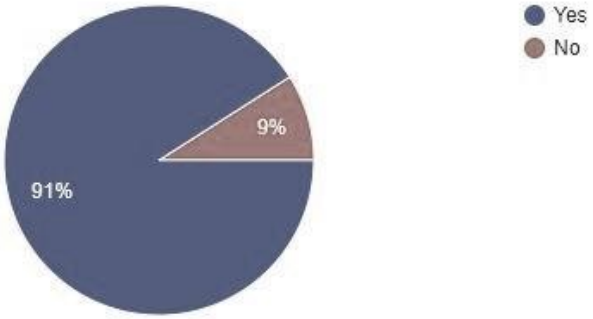
Do you own folding pieces of furniture?

122 απαντήσεις



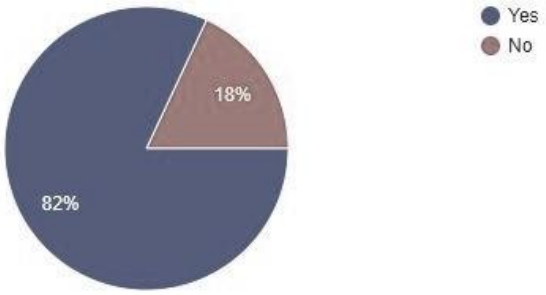
Would you purchase folding furniture instead of static furniture?

122 απαντήσεις



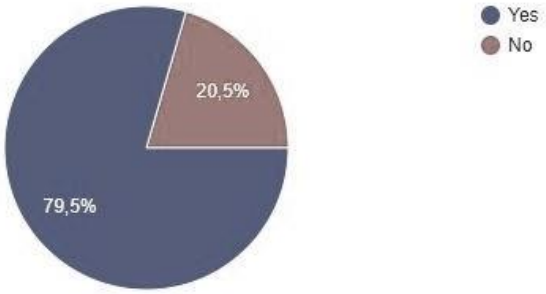
Do you need to adopt space-saving strategies in your house or office?

122 απαντήσεις



Do you consider furniture portability as an important factor for selecting a furniture piece?

122 απαντήσεις



What is the approximate area of your house or apartment?

122 απαντήσεις